ANTENNA UNIT AND RECEIVING CIRCUIT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an antenna unit and a receiver.

2. Description of the Related Art

Digital audio broadcasting in the U.S. is called DARS (Digital Audio Radio Service). To realize stable reception in a receiver mounted in a vehicle, DARS uses both satellite waves and terrestrial waves.

That is, DARS uses the 2.3 GHz band. As shown in part B in Fig. 8, two services are transmitted. In this instance, each of the services uses a frequency bandwidth of 12.5 MHz. As shown in part A in Fig. 8, one service comprises two ensembles A and B. Each of the ensembles A and B provides 50 channels of programs (contents). Accordingly, one service provides 100 channels of programs.

The ensemble A is transmitted by signals A1, A2, and A3. The ensemble B is transmitted by signals B1, B2, and B3. That is, the contents of the signals A1, A2, and A3 are identical to each other. The contents of the signals B1, B2, and B3 are also identical to each other. Consequently, when any one of the signals A1, A2, and A3 can be received, the programs of the ensemble A can be received. Similarly, when

any one of the signals B1, B2, and B3 can be received, the programs of the ensemble B can be received.

As shown in part A in Fig. 8, the signals A1 to A3 and the signals B1 to B3 are arranged in order of frequency, so that the signals A1, A2, and A3 and the signals B3, B2, and B1 are symmetrically arranged with respect to the central frequency f_c between the signals A3 and B3.

The signals A1, A2, B1, and B2 are QPSK (Quadrature Phase Shift Keying) signals. The signals A1 and B1 are transmitted from a broadcasting satellite BS1 located over the Western U.S. and the signals A2 and B2 are transmitted from a broadcasting satellite BS2 located over the Eastern U.S. (strictly, the satellites BS1 and BS2 are positioned on the equator at a longitude corresponding to the Western and Eastern U.S.). The signals A3 and B3 are OFDM (Orthogonal Frequency Division Multiplex) signals and are transmitted from an antenna on the ground.

Therefore, since the signals A1, A2, B1, and B2 are satellite waves and a diversity effect is obtained by the satellites BS1 and BS2, the broadcasts can be received all over the U.S. In some cases, high-rise buildings block radio waves. The terrestrial-wave signals A3 and B3 compensate to the blocked waves. Consequently, in the receiver mounted in a car, even when the radio waves vary strongly due to the motion of the car, the broadcasts can

still be easily received.

When the above-mentioned DARS signals are received by the receiver mounted in the car, a receiving antenna thereof has low directivity in order to obtain uniform sensitivity irrespective of the direction of travel of the car. However, the gain of a low-directivity receiving antenna is small.

Consequently, the reception levels of the signals A1, A2, B1, and B2 transmitted from the satellites BS1 and BS2 are considerably low. Actually, the reception levels of the signals A1 to B2 are higher than the noise level of the receiving antenna by 10 dB to 20 dB; that is, the levels are substantially equal to -100 dBm to 90 dBm. When the DARS signals are received, therefore, a high-frequency amplifier for amplifying the output of the receiving antenna is needed. In addition, a high-frequency amplifier with sufficiently low noise is needed.

On the other hand, the reception levels of the signals A3 and B3 transmitted from the antenna on the ground vary strongly depending on the distance from the transmitting antenna to the receiving antenna, namely, the levels are substantially equal to -90 dBm to 0 dBm. When the signals A3 and B3 are received near the transmitting antenna, the reception levels rise considerably, so that the high-frequency amplifier becomes saturated, causing large distortion.

Consequently, in consideration of the above description, a high-frequency amplifier which has a low noise level and small distortion even when the input level varies over a range of 100 dB is needed at an antenna input stage of the receiver.

Generally, when the reception level varies, AGC (Automatic Gain Control) is performed to stabilize the signal level. In case of a DARS receiver, the AGC must respond to a variable range of the reception level as high as 100 dB.

Furthermore, when the DARS receiver is mounted in the car, an antenna thereof is disposed on a portion, in which reception interference is small, for example, on the roof. Since the receiver is arranged in the car, the antenna is connected to the receiver through a cable. As mentioned above, however, the DARS broadcasts use the 2.3 GHz band, so attenuation caused by the cable is large. Generally, attenuation of about 10 dB is caused. Accordingly, when the antenna is simply connected to the receiver through the cable, it is difficult to receive the satellite-wave signals A1 to B2.

Generally, in such a case, a high-frequency amplifier is integrated with the antenna, a received signal of the antenna is amplified by the high-frequency amplifier, and the resultant signal is supplied to the receiver through the

cable. In this instance, the necessary operating voltage for the high-frequency amplifier is supplied from the receiver through the cable.

However, to perform AGC in the high-frequency amplifier integrated with the antenna, an AGC voltage is generated from the receiver, thus necessitating a line for supplying the AGC voltage to the high-frequency amplifier. Consequently, a special cable or connector is needed.

To perform AGC in the high-frequency amplifier, the high-frequency amplifier should comprise a variable gain amplifier. The NF (Noise Figure) of the variable gain amplifier is generally lower than that of a fixed gain amplifier. Accordingly, the variable gain amplifier cannot be used as a high-frequency amplifier in which low noise is required.

The present invention intends to solve the above problems.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an antenna unit including a high-frequency amplifier for amplifying a reception signal received by an antenna, wherein an output signal of the high-frequency amplifier is supplied to a receiver through a regular output cable such as a coaxial cable, an operating voltage is

supplied from the receiver to the high-frequency amplifier
through the output cable, and a signal to control the gain
is supplied from the receiver through the output cable.

Particularly, an antenna unit includes: a high-
frequency amplifier for amplifying a reception signal
received by an antenna; an attenuator circuit; and a
switching circuit, wherein, an operating voltage is supplied
from a receiver, to which an output signal of the high-
frequency amplifier is supplied through an output cable, to
the high-frequency amplifier through the output cable; a
control signal is supplied from the receiver to the
switching circuit through the output cable; and the
switching circuit is controlled in accordance with the
control signal to selectively connect one of the high-
frequency amplifier and the attenuator circuit to a signal
line between the antenna and the output cable.

Another object of the present invention is to provide a
receiver using an antenna unit that has a high-frequency
amplifier, outputs a signal received by an antenna with a
predetermined gain through a regular output cable such as a
coaxial cable, and is capable of changing the gain. The
receiver includes: a voltage source of an operating voltage
for the high-frequency amplifier; and a control circuit for
controlling the magnitude of the operating voltage, wherein,
the operating voltage from the voltage source is supplied to

the high-frequency amplifier of the antenna unit through the
output cable; and the control circuit controls the magnitude
of the operating voltage to change the gain.

Particularly, a receiver uses an antenna unit which
transmits a signal received by an antenna with a
predetermined gain to an output cable and which is capable
of changing the gain in accordance with a first control
signal. The receiver includes: a connector which is
connected to the output cable; a receiving circuit having at
least a high-frequency amplifier, a variable attenuator
circuit, and a switching circuit; and a generator circuit
for generating the first control signal and second and third
control signals from an AGC voltage corresponding to the
output level of the receiving circuit, wherein, an operating
voltage is supplied to the antenna unit through the output
cable; the first control signal generated from the generator
circuit is supplied to the antenna unit through the output
cable to change the gain; the switching circuit is
controlled in accordance with the second control signal to
selectively connect one of the high-frequency amplifier and
the variable attenuator circuit to a signal line between the
connector and a circuit in the subsequent stage; and the
third control signal controls the gain of the variable
attenuator circuit.

Consequently, the high-amplifier, attenuator circuit,

and variable attenuator circuit are controlled according to a received signal strength, so that AGC with a wide dynamic range is performed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram showing an embodiment of the present invention;

Fig. 2 is a block diagram showing another embodiment of the invention;

Fig. 3 includes characteristic graphs A to F for explaining the invention;

Fig. 4 shows characteristic graphs A and B for explaining the invention;

Fig. 5 includes characteristic graphs A to C for explaining the invention;

Figs. 6A to 6C are frequency spectrum diagrams for explaining the invention;

Fig. 7 shows characteristic graphs A to C for explaining another embodiment of the invention; and

Fig. 8 is a frequency spectrum diagram for explaining DARS.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figs. 1 and 2 show an example of a case where the present invention is applied to an antenna unit and a

receiver for receiving DARS signals. Reference numeral 10
denotes an antenna unit and reference numeral 30 indicates a
receiver.

In the antenna unit 10, a receiving antenna 11 for the
DARS signals A1 to B3 is connected to a high-frequency
amplifier 13 or an attenuator circuit 14 via a switching
circuit 12. In this case, to selectively connect the
antenna 11 to one of the high-frequency amplifier 13 and the
attenuator circuit 14, the switching circuit 12 has a
switching element such as a gallium arsenide FET (field
effect transistor), in which the loss or noise is low when
turned on, which exhibits excellent isolation when turned
off, and which has excellent high-frequency characteristics.
The switching circuit 12 is represented as a single-pole
double-throw switch in Fig. 1.

The high-frequency amplifier 13 comprises a low-noise
amplifier. A gain G_{13} thereof is fixed at, for example, $G_{13} =$
14 dB. Moreover, a gain G_{14} of the attenuator circuit 14 is
fixed at, for example, $G_{14} = -6$ dB. In the following
description, the gain is expressed in decibels (dB).

Either the high-frequency amplifier 13 or the
attenuator circuit 14 is connected to a band-pass filter 16
through a switching circuit 15. In this case, the switching
circuit 15 is constructed in a manner similar to the
switching circuit 12 and selectively connects either the

high-frequency amplifier 13 or the attenuator circuit 14 to
a high-frequency signal line. The band-pass filter 16
comprises, e.g., an SAW (Surface Acoustic Wave) filter and
has characteristics for allowing the two services shown in
part B in Fig. 8 to pass through.

Further, an output terminal of the band-pass filter 16
is connected to an input terminal of a high-frequency
amplifier 17 comprising a fixed-gain low-noise amplifier.
An output terminal on the hot side of the amplifier 17 is
connected to the conductor (hot-side line) of a coaxial
cable 18 via a capacitor C11 for DC blocking. In this case,
the coaxial cable 18 is a regular cable. The cable supplies
the signals A1 to B3 received by the antenna unit 10 to the
receiver 30 and also supplies an operating voltage for the
antenna unit 10 and a control voltage for the gain of the
antenna unit 10 from the receiver 30 to the antenna unit 10.
The cable is connected to a connector plug 19 at the right
in Fig. 1.

The connection point between the capacitor C11 and the
conductor of the cable 18 is connected to a power supply
line on the hot side of the amplifiers 13 and 17 through a
high-frequency choke coil L11 and a resistor R11. A
capacitor C12 is connected between the power supply line on
the hot side and the ground. Consequently, when the
operating voltage for the antenna unit 10 is supplied from

the receiver 30 via the coaxial cable 18, a DC voltage V_{PWR} occurs at the connection point between the elements R11 and C12. The voltage V_{PWR} is supplied to the amplifiers 13 and 17 as an operating voltage thereof. As will be explained below, the voltage V_{PWR} is a voltage that changes to a voltage V_H or a voltage V_L. For example, V_H is equal to 3 V and V_L is equal to 2.7 V.

Furthermore, the voltage V_{PWR} is supplied to a voltage detector circuit 21 to detect whether $V_{PWR} = V_L$ or $V_{PWR} = V_H$. A detection output of the detector circuit 21 is supplied to the switching circuits 12 and 15 as a control voltage thereof. When $V_{PWR} = V_L$, as shown in Fig. 1, the switching circuits 12 and 15 are connected to the amplifier 13. When $V_{PWR} = V_H$, contrary to the situation shown in Fig. 1, they are connected to the attenuator circuit 14.

The whole antenna unit 10 is held in one enclosure (not shown). The coaxial cable 18 extends from the enclosure. Accordingly, the antenna unit 10 is disposed on, for example, the roof of a car and the cable 18 is introduced into the car.

As shown in Fig. 2, in the receiver 30, the hot side of a connector jack 31, to which the connector plug 19 of the antenna unit 10 is connected, is connected to one of a high-frequency amplifier 33 and a variable attenuator circuit 34 through a capacitor C31 and a switching circuit 32. In this

case, the switching circuit 32 is constructed in a manner similar to the switching circuit 12. The connector jack 31 is selectively connected to one of the high-frequency amplifier 33 and the variable attenuator circuit 34.

The high-frequency amplifier 33 comprises a low-noise amplifier. A gain G_{33} thereof is fixed. A control voltage V_{ATT} changes a gain G_{34} of the variable attenuator circuit 34.

One of the high-frequency amplifier 33 and the attenuator circuit 34 is connected to a variable attenuator circuit 36 via a switching circuit 35. The switching circuit 35 is also constructed in a manner similar to the switching circuit 12. The switching circuit 35 selectively connects one of the high-frequency amplifier 33 and the variable attenuator circuit 34 to a high-frequency signal line. The control voltage V_{ATT} varies a gain G_{36} of the variable attenuator circuit 36.

As will be explained below, the received signals A1 to A3 and B1 to B3, subjected to AGC, are generated from the variable attenuator circuit 36. In the following description, for the sake of simplicity, as shown in Fig. 6A, the signals A1 and A2 are combined into a signal A12 and the signals B1 and B2 are combined into a signal B12.

That is, the signals A12, A3, B12, and B3 (signals A1 to B3) generated from the variable attenuator circuit 36 are supplied to a first mixer circuit 39 through a high-

frequency amplifier 37, comprising a low-noise amplifier, and a band-pass filter 38. A first local oscillation signal S_{LO} is also supplied from a first local oscillator circuit 41 to the first mixer circuit 39. The signals A12 to B3 are frequency-converted into first intermediate-frequency signals. The band-pass filter 38 comprises, for example, an SAW filter and has characteristics for allowing the two services shown in part B in Fig. 8 to pass through.

When the ensemble A is received (the signals A1 to A3 are needed), as shown by a solid line in Fig. 6A, the frequency of the first local oscillation signal S_{LO} is set to a predetermined frequency f_L that is lower than those of the signals A12 and A3. Accordingly, as shown in Fig. 6B, the signal A12 is frequency-converted into a first intermediate-frequency signal S_{IF12} (intermediate frequency f_{IFL12}), the signal A3 is frequency-converted into a first intermediate-frequency signal S_{IF3} (intermediate frequency f_{IF3}), the signal B12 is frequency-converted into a first intermediate-frequency signal S_{IF45}, and the signal B3 is frequency-converted into a first intermediate-frequency signal S_{IF6}.

In consideration of image characteristics, the first intermediate-frequencies f_{IF12} and f_{IF3} cannot be lowered much. Since a frequency band of 2.3 GHz is used for broadcasting, the first intermediate frequencies f_{IF12} and f_{IF3} are set to 100 MHz or higher. For example,

$f_{IF12} \approx 113$ MHz, $f_{IF3} \approx 116$ MHz

When the ensemble B is received (the signals B1 to B3 are needed), as shown by a broken line in Fig. 6A, the frequency of the first local oscillation signal S_{L0} is set to a predetermined frequency f_H that is higher than those of the signals B12 and B3. Accordingly, as shown in Fig. 6C, the signal B12 is frequency-converted into the first intermediate-frequency signal S_{IF12} (intermediate frequency f_{IF12}), the signal B3 is frequency-converted into the first intermediate-frequency signal S_{IF3} (intermediate frequency f_{IF3}), and the signals A12 and A3 are frequency-converted into the first intermediate-frequency signals S_{IF45} and S_{IF6}, respectively.

In both the case where the ensemble A is received and the case where the ensemble B is received, the intermediate-frequency signals S_{IF12} to S_{IF6} are supplied to a band-pass filter 43L, serving as a first intermediate-frequency filter, through an intermediate-frequency amplifier 42, so that the intermediate-frequency signal S_{IF12} is generated. The signal S_{IF12} is supplied to a second mixer circuit 44L. A second local oscillation signal having a predetermined frequency is generated from a second local oscillator circuit 45. The signal is also supplied to the second mixer circuit 44L, so that the signal S_{IF12} is frequency-converted into a second intermediate-frequency signal. The signal is supplied to a

demodulator circuit 47L through a variable gain amplifier
46L for AGC to demodulate a digital audio signal for a
target program. The signal is then supplied to a combiner
circuit 48.

The signals S_{IF12} to S_{IF6} from the mixer circuit 39 are
supplied to a band-pass filter 43H, acting as a first
intermediate-frequency filter, to generate the intermediate-
frequency signal S_{IF3}. The signal S_{IF3} is supplied to a second
mixer circuit 44H. The second local oscillation signal from
the second local oscillator circuit 45 is supplied to the
mixer circuit 44H, so that the signal S_{IF3} is frequency-
converted into a second intermediate-frequency signal. The
signal is supplied to a demodulator circuit 47H through a
variable gain amplifier 46H for AGC to demodulate a digital
audio signal of a target program. The signal is then
supplied to the combiner circuit 48.

In the combiner circuit 48, either the signal from the
demodulator circuit 47L or the signal from the demodulator
circuit 47H is selected or both the signals are combined,
and the resultant signal is generated at an output terminal
49.

At that time, a part of the second intermediate-
frequency signal is supplied from the demodulator circuit
47L to a level detector circuit 51L to generate an AGC
voltage. The AGC voltage is supplied as a gain control

signal to the amplifier 46L, so that the second intermediate-frequency signal of the signal A12 or B12 is subjected to AGC. Further, a part of the second intermediate-frequency signal is supplied from the demodulator circuit 47H to a level detector circuit 51H to generate an AGC voltage. The AGC voltage is supplied as a gain control signal to the amplifier 46H, so that the second intermediate-frequency signal of the signal A3 or B3 is subjected to AGC.

Consequently, the frequency of the first local oscillation signal S_{LO} is changed into one of the frequencies f_L and f_H, so that the digital signal of the ensemble A or that of the ensemble B is outputted at the terminal 49.

At that time, when the ensemble A is received, one of the digital signal demodulated from the received signal A12 and the digital signal demodulated from the received signal A3 is selected or both the signals are combined, and the resultant signal is outputted at the terminal 49. Consequently, the digital signal having few errors can be obtained irrespective of the receiving conditions. For the same reason, when the ensemble B is received, the digital signal having few errors can be obtained irrespective of the receiving conditions.

To perform AGC on the signals A1 to B3 in high-frequency stages of the antenna unit 10 and the receiver 30,

according to the invention, the antenna unit 10 and the receiver 30 are constructed as follows. That is, as mentioned above, the antenna unit 10 is provided with the circuits 12 to 15 including the switching circuits 12 and 15 and the voltage detector circuit 21 in the high-frequency stage, and the receiver 30 includes the circuits 32 to 36 in the high-frequency stage.

In this case, the gain G_{34} of the variable attenuator circuit 34 and the gain G_{36} of the variable attenuator circuit 36 change logarithmically with respect to the control voltage V_{ATT}. That is, decibel values of the gains G_{34} and G_{36} change linearly.

A part of the first intermediate-frequency signals S_{IF12} and S_{IF3} outputted from the intermediate-frequency amplifier 42 is supplied to a level detector circuit 52, thereby generating an AGC voltage V_{AGC} whose level increases when the levels of the received signals A1 to B3 increase. The AGC voltage V_{AGC} is supplied to a control voltage generator circuit 53, thereby generating control voltages V_{ANT}, V_{SW}, and V_{ATT}, which change with respect to the AGC voltage V_{AGC} as shown in, for example, graphs A to C in Fig. 3.

In other words, for the sake of simplicity, it is assumed that a minimum value of each of the voltages V_{AGC} and V_{ATT} is equal to 0. It is also assumed that two predetermined values in the AGC voltage V_{AGC} are set to

values V_1 and V_2 ($V_1 < V_2$).

When $V_{AGC} < V_2$, the control voltage V_{AN2} becomes high ("H"). When $V_{AGC} \geq V_2$, the voltage V_{AN2} becomes low ("L"). When $V_{AGC} < V_1$, the control voltage V_{SW} becomes high ("H"). When $V_{AGC} \geq V_1$, the voltage V_{SW} becomes low ("L").

As the AGC voltage V_{AGC} increases from the minimum value of 0 V, the control voltage V_{ATT} increases from the minimum value of 0 V. When $V_{AGC} = V_1$, the voltage temporarily decreases to the minimum value of 0 V. After that, as the AGC voltage V_{AGC} increases, the voltage increases from the minimum value of 0 V. When $V_{AGC} = V_2$, the control voltage V_{ATT} decreases by a predetermined value ΔV. After that, as the AGC voltage V_{AGC} increases, the voltage increases again. At that time, the rate of change of the voltage V_{ATT} in the case where $V_1 < V_{AGC}$ is 1/2 that of the voltage V_{ATT} in the case where $0 \leq V_{AGC} < V_1$.

The control voltage V_{ATT} is supplied as a control signal for the gains G_{34} and G_{36} to the variable attenuator circuits 34 and 36. As the voltage V_{ATT} becomes larger, the gains G_{34} and G_{36} are set smaller (each attenuation is larger). When $V_{ATT} = 0$ V (minimum value), each of the gains G_{34} and G_{36} of the variable attenuator circuits 34 and 36, namely, the maximum gain thereof (minimum attenuation) is set to a value G_0. Generally, although the value G_0 approximates to 0 dB, it has a negative value.

The control voltage V_{SW} is supplied to the switching circuits 32 and 35 as a switching control signal thereof. When V_{SW} is high ("H"), the switching circuits 32 and 35 are connected to the amplifier 33. When V_{SW} is low ("L"), they are connected to the attenuator circuit 34.

Furthermore, the control voltage V_{ANT} is supplied to a base of a transistor Q51. A power supply terminal T51 is connected to the hot side of the connector jack 31 through a diode D51 and a high-frequency choke coil L51. An emitter and a collector of the transistor Q51 are connected in parallel to the diode D51. A capacitor C51 is connected between the connection point of the elements D51 and L51 and the ground.

In such a configuration, a voltage $+V_{CC}$ of the terminal T51 is generated as the voltage V_{PWR} through the following path: the diode D51 or transistor Q51 → coil L51 → jack 31 → plug 19 → coaxial cable 18 → coil L11 → resistor R11. Since the voltage V_{PWR} is supplied to the amplifiers 13 and 17 as an operating voltage thereof, the antenna unit 10 becomes active.

In this case, when it is assumed that:

V_{D51} : voltage drop of the diode D51, and

V_{QEC51} : voltage drop between the emitter and the collector of the transistor Q51

then, generally:

$$V_{D51} > V_{QEC51}.$$

Consequently, when the transistor Q51 is turned off:

$$V_{PWR} = V_{cc} - V_{D51} - V_{R11}$$

where V_{R11} is the voltage drop of the resistor R11.

When the transistor Q51 is turned on:

$$V_{PWR} = V_{cc} - V_{QEC51} - V_{R11}$$

The power supply voltage $+V_{cc}$ and the type (standard) of the diode D51 are preliminarily selected. For example, in the case where a Schottky diode is used as the diode D51, when the transistor Q51 is turned off:

$$V_{PWR} = V_{cc} - V_{D51} - V_{R11}$$
$$= V_L$$

When the transistor Q51 is turned on:

$$V_{PWR} = V_{cc} - V_{QEC51} - V_{R11}$$
$$= V_H$$

When the antenna unit 10 is in the operating state, the signals A1 to B3 received by the antenna 11 are supplied to the amplifier 37 through the following signal path: the antenna 11 → switching circuit 12 → amplifier 13 or attenuator circuit 14 → switching circuit 15 → band-pass filter 16 → amplifier 17 → capacitor C11 → coaxial cable 18 → plug 19 → jack 31 → capacitor C31 → switching circuit 32 → amplifier 33 or attenuator circuit 34 → switching circuit 35 → attenuator circuit 36. Consequently, as mentioned above, the DARS program can be received.

In this case, as shown in Figs. 1 and 2, it is assumed that:

G_{10}: gain of the portion from the switching circuit 12 to the switching circuit 15,

G_{17}: gain of the amplifier 17,

G_{30}: gain of a range from the switching circuit 32 to the switching circuit 35, and

G_{36}: gain of the attenuator circuit 36,

then a total gain G_{ALL} of the portion from the output terminal of the antenna 11 to the input terminal of the amplifier 37 is:

$G_{ALL} = G_{10} + G_{17} + G_{30} + G_{36} +$ other losses   ... (A)

Accordingly, the relationships between the gains G_{10}, G_{17}, G_{30}, and G_{36} and the AGC voltage V_{AGC} are as follows.

[1] Gain G_{10}

The switching circuits 12 and 15 are controlled by a detection output of the detector circuit 21, so that the gain G_{10} changes as described below.

(1) When $0 \leq V_{AGC} < V_1$

As shown in graph A in Fig. 3, since V_{ANT} is high ("H"), the transistor Q51 is turned off. In the antenna unit 10, $V_{PWR} = V_L$. The detector circuit 21 detects the fact that $V_{PWR} = V_L$. Due to the detection output thereof, the switching circuits 12 and 15 are connected to the amplifier 13, as shown in Fig. 1. As shown in graph D in Fig. 3, therefore,

the gain G_{10} is equivalent to the gain G_{13} of the amplifier 13 in the antenna unit 10.

(2) When $V_1 \leq V_{AGC} < V_2$

As shown in graph A in Fig. 3, in this case as well, V_{ANT} is high ("H"). Accordingly, as shown in graph D in Fig. 3, the gain G_{10} is equivalent to the gain G_{13} of the amplifier 13, as in case (1).

(3) When $V_2 \leq V_{AGC}$

As shown in graph A in Fig. 3, since V_{ANT} is low ("L"), the transistor Q51 is turned on, so that $V_{PWR} = V_H$. The detector circuit 21 detects the fact that $V_{PWR} = V_H$. Due to the detection output thereof, the switching circuits 12 and 15 are connected to the attenuator circuit 14, contrary to the situation shown in Fig. 1. As shown in graph D in Fig. 3, therefore, the gain G_{10} is equivalent to the gain G_{14} of the attenuator circuit 14.

When the voltage changes from case (2) to case (3), the gain G_{10} decreases from the present gain G_{13} to the gain G_{14}. The gain difference $(G_{13} - G_{14})$ is set as a value ΔG_1.

[2] Gain G_{17}

Since the gain G_{17} is the gain of the amplifier 17, it is constant irrespective of the value of the AGC voltage V_{AGC}.

[3] Gain G_{36}

Before describing the gain G_{30}, the gain G_{36} will be described here. The control voltage V_{ATT} controls the gain

G_{36} as follows.

(1) When $0 \leq V_{AGC} < V_1$

As shown in graph C in Fig. 3, the control voltage V_{ATT} monotonically increases from the minimum value of 0 V in response to an increase of the AGC voltage V_{AGC}. Accordingly, as shown in graph F in Fig. 3, the gain G_{36} monotonically decreases from a maximum value G_0 in response to the increase of the AGC voltage V_{AGC}.

(2) When $V_1 \leq V_{AGC} < V_2$

In this case as well, as shown in graph C in Fig. 3, the control voltage V_{ATT} monotonically increases from the minimum value of 0 V in response to the increase of the AGC voltage V_{AGC}. Consequently, as shown in graph F in Fig. 3, the gain G_{36} monotonically decreases from the maximum value G_0 in response to the increase of the AGC voltage V_{AGC}.

Since the rate of decrease of the control voltage V_{ATT} in case (2) is 1/2 that in case (1), the rate of decrease of the gain G_{36} in case (2) is also 1/2 that in case (1). When the voltage changes from case (1) to case (2), the gain G_{36} increases from the present gain to the gain G_0. The gain difference in this case is set as a value ΔG_4.

(3) When $V_2 \leq V_{AGC}$

As shown in graph C in Fig. 3, when the voltage changes from case (2) to case (3), the control voltage V_{ATT} decreases from the present voltage by a value ΔV. After that, the

voltage monotonically increases in response to the increase
of the AGC voltage V_{AGC}.

As shown in graph F in Fig. 3, therefore, when the
voltage changes from case (2) to case (3), the gain G_{36}
increases from the present gain value by a value ΔG_3
corresponding to the voltage drop ΔV. After that, the
voltage monotonically decreases in response to the increase
of the AGC voltage V_{AGC}.

Since the rate of decrease of the control voltage V_{ATT} in
case (3) is 1/2 that in case (1), the rate of decrease of
the gain G_{36} in case (3) is also 1/2 that in case (1).

[4] Gain G_{30}

The switching circuits 32 and 35 are controlled by the
control voltage V_{SW} and the attenuator circuit 34 is
controlled by the control voltage V_{ATT}, so that the gain G_{30}
is changed as follows.

(1) When $0 \leq V_{AGC} < V_1$

As shown in graph B in Fig. 3, since V_{SW} is high ("H"),
the switching circuits 32 and 35 are connected to the
amplifier 33 as shown in Fig. 2. As shown in graph E in Fig.
3, therefore, the gain G_{30} is equivalent to the gain G_{33} of
the amplifier 33.

(2) When $V_1 \leq V_{AGC} < V_2$

As shown in graph B in Fig. 3, since V_{SW} is low ("L"),
the switching circuits 32 and 35 are connected to the

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attenuator circuit 34, contrary to the case shown in Fig. 2.
Consequently, the gain G_{30} is equivalent to the gain G_{34} of
the attenuator circuit 34.

In this case, since the attenuator circuit 34 is
controlled by the control voltage V_{ATT} as in the same way as
the attenuator circuit 36, the gain G_{34} changes in the same
way as the gain G_{36}. When the voltage changes from case (1)
to case (2), the gain G_{36} decreases from the present gain G_{33}
to the gain G_0. Such a gain difference $(G_{33} - G_0)$ is set as a
value ΔG_2.

(3) When $V_2 \leq V_{AGC}$

As shown in graph B in Fig. 3, in this case as well, V_{SW}
is low ("L"). Accordingly, the switching circuits 32 and 35
are connected to the attenuator circuit 34, contrary to the
case shown in Fig 2. Consequently, the gain G_{30} is
equivalent to the gain G_{34} of the attenuator circuit 34. In
this case as well, since the attenuator circuit 34 is
controlled by the control voltage V_{ATT} as in the same way as
the attenuator circuit 36, the gain G_{34} changes in a manner
similar to the gain G_{36}.

[5] Total gain G_{ALL}

Since the total gain G_{ALL} is shown by equation (A) above,
it has a characteristic obtained by combining
characteristics shown in graphs D to F in Fig. 3. The gains
or characteristics of the respective circuits are initially

set to the following values:

$\Delta G_1 = 2 \cdot \Delta G_3$, and

$\Delta G_2 = \Delta G_4$.

In equation (A), consideration is made with respect to a combined gain ($G_{30} + G_{36}$) of the gains G_{30} and G_{36} with reference to Fig. 4. The characteristic indicated by the broken lines in graph A in Fig. 4 is the same as that in graph E in Fig. 3, namely, the characteristic of the gain G_{30}. The characteristic of graph B in Fig. 4 is the same as that of graph F in Fig. 3, namely, the characteristic of the gain G_{36}. Moreover, for the sake of simplicity, it is assumed that $G_0 = 0$ dB.

When the characteristic of the gain G_{36} is shown as a graph on the basis of the characteristic of the gain G_{30} as a reference, the characteristic indicated by solid lines is obtained. It indicates the characteristic of the gain ($G_{30} + G_{36}$). That is, when the AGC voltage V_{AGC} changes from case (1) to case (2), the gain G_{30} decreases from the gain G_{33} by the gain ΔG_2. At that time, the gain G_{36} increases by the gain ΔG_4 and $\Delta G_2 = \Delta G_4$. Accordingly, when the AGC voltage V_{AGC} changes from case (1) to case (2), there is no step in the characteristic of the gain ($G_{30} + G_{36}$).

Since the rate of decrease of each of the gains G_{30} and G_{36} in case (2) is 1/2 that of the gain G_{36} in case (1), the rate of decrease of the gain ($G_{30} + G_{36}$) in case (2) is

equivalent to that of the gain G_{36} in case (1).

Consequently, the characteristic of the gain $(G_{30} + G_{36})$ in cases (1) and (2) continuously decreases at a fixed rate, as shown by one solid line in graph A in Fig. 4.

When the AGC voltage V_{AGC} changes from case (2) to case (3), the gains G_{30} and G_{36} both increase by the gain ΔG_3. Accordingly, when the AGC voltage V_{AGC} changes from case (2) to case (3), the gain $(G_{30} + G_{36})$ increases by the gain $2 \cdot \Delta G_3$.

Furthermore, since the rate of decrease of each of the gains G_{30} and G_{36} in case (3) is 1/2 that of the gain G_{36} in case (1), the rate of decrease of the gain $(G_{30} + G_{36})$ in case (3) is equivalent to that of the gain G_{36} in case (1).

Accordingly, as shown by the solid lines in graph A in Fig. 5, when the AGC voltage V_{AGC} changes from case (2) to case (3), the characteristic of the gain $(G_{30} + G_{36})$ in case (3) increases by the gain $2 \cdot \Delta G_3$ and is in parallel with that in case (2).

In equation (A), since the gains $(G_{30} + G_{36})$ and G_{10} are further combined, a combined gain $(G_{30} + G_{36} + G_{10})$ is indicated by the characteristic shown in graph C in Fig. 5. That is, the characteristic in graph A in Fig. 5 is the same as that shown by the solid lines in graph A in Fig. 4, and indicates the characteristic of the gain $(G_{30} + G_{36})$. The characteristic in graph B in Fig. 5 is the same as that in graph D in Fig. 3, and indicates the characteristic of the

gain G_{10}.

Since the gain $(G_{30} + G_{36})$ is added to the gain G_{10}, in cases (1) and (2), the characteristic of the gain $(G_{30} + G_{36})$ uniformly increases by the gain G_{13}. In case (3), the characteristic of the gain $(G_{30} + G_{36})$ uniformly increases by the gain G_{14}.

When the AGC voltage V_{AGC} changes from case (2) to case (3), the gain $(G_{30} + G_{36})$ increases by the gain $2 \cdot \Delta G_3$. The gain G_{10} decreases by the gain ΔG_1 and $\Delta G_1 = 2 \cdot \Delta G_3$. Consequently, when the AGC voltage V_{AGC} changes from case (2) to case (3), the characteristic of the gain $(G_{30} + G_{36} + G_{10})$ has no step.

In cases (1), (2), and (3), the portions of the characteristic of the gain $(G_{30} + G_{36})$ are parallel to each other. Accordingly, as shown by one line in graph C in Fig. 5, the characteristic of the gain $(G_{30} + G_{36} + G_{10})$ in cases (1) to (3) continuously decreases at a fixed rate.

In equation (A), the total gain G_{ALL} is obtained by combining the gain $(G_{30} + G_{36} + G_{10})$ having the characteristic shown in graph C in Fig. 5, the gain G_{17} which is constant irrespective of the AGC voltage V_{AGC}, and the losses. Accordingly, the characteristic of the total gain G_{ALL} continuously changes linearly with respect to the AGC voltage V_{AGC} in a manner similar to the case of the characteristic of the gain $(G_{30} + G_{36} + G_{10})$ shown in graph C

in Fig. 5.

As mentioned above, when the foregoing antenna unit 10 and the receiver 30 are used, the total gain G_{ALL} between the output terminal of the antenna 11 and the input terminal of the amplifier 37 continuously changes uniformly over a wide range of the AGC voltage V_{AGC}. Consequently, AGC can be effectively performed over a wide range of received signal strength.

In this case, as has been obviously understood from the description regarding Figs. 3 to 5, in the case where the received signal strength is low and the AGC voltage V_{AGC} is low, that is, in case (1), the high-frequency amplifiers 13 and 33 are used. Consequently, the received signal can be amplified to a sufficient level in a suitable NF state.

In the case where the received signal strength is high and the AGC voltage V_{AGC} is high, that is, in case (3), the high-frequency amplifiers 13 and 33 are not used and the attenuator circuits 14, 34, and 36 are used. Consequently, the received signal has no distortion due to the saturation of the high-frequency amplifiers and the received signal can be controlled at a suitable level.

Furthermore, in the antenna unit 10, since the gain of the antenna unit 10 can be changed by switching between the high-frequency amplifier 13 and the attenuator circuit 14, it is not necessary for the high-frequency amplifier 10 to

comprise a variable gain amplifier. Accordingly, the NF does not deteriorate.

When the antenna unit 10 is disposed on the roof of a car and the receiver 30 is arranged in the car, the operating voltage V_{PWR} can be supplied from the receiver 30 to the antenna unit 10 through the coaxial cable 18.

In this case, the operating voltage V_{PWR} changes according to the AGC voltage V_{AGC}. The amplifier 13 and the attenuator circuit 14 are alternately selected in the antenna unit 10 according to a change of the operating voltage V_{PWR}. Consequently, when the gain of the antenna unit 10 is changed, a regular coaxial cable can be used as the cable 18. A special cable is not needed and an additional cable is not needed.

For example, as shown in Fig. 7, in a case where V_{AGC} = V_1 and V_2, when the control voltages V_{ANT}, V_{SW}, and V_{ATT} have hysteresis characteristics, switching between the switching circuits 12 and 15, switching between the switching circuits 32 and 35, and changes in the gains G_{34} and G_{36} of the attenuator circuits 34 and 36 in the case where V_{AGC} = V_1 and V_2 do not become unstable.

Each of the switching circuits 12, 15, 32, and 35 can comprise a PIN diode or transistor. Furthermore, the above description has been made with respect to the case where the present invention was applied to the receiver 30 and the

antenna unit 10 for DARS. Similarly, the present invention
can be applied when the receiver is separated from the
antenna unit and AGC is needed over a wide range of the
received signal strength.

According to the invention, AGC can be effectively
performed over a wide range of the received signal strength.
In this case, when the level of the received signal is low,
the received level can be amplified to a sufficient level in
a suitable NF state. When the level of the received signal
is high, there is no distortion caused by saturation of the
high-frequency amplifier and the received signal can be
controlled at a suitable level.

Moreover, in the antenna unit, the NF of the received
signal is not deteriorated. When the antenna unit is
disposed on the roof of a car and the receiver is arranged
in the car, the operating voltage can be supplied from the
receiver to the antenna unit through the coaxial cable.
Furthermore, the gain of the antenna unit can be also
changed via the coaxial cable. Since a regular coaxial
cable can be used, neither a special cable nor an additional
cable is needed.